

Technical methods of improving the biomechanics of feet in people with diabetes

K.A. Koreyba^{1*}, L.N. Gatina², and D.K. Koreiba³

¹Kazan State Medical University, Ministry of Health of the Russian Federation, Department of Surgery, 420012, Kazan, Russia

²Clinical Hospital "Russian Railway - Medicine", Department of Purulent Surgery, Kazan, Russia

³Kazan National Research Technological University" - Institute of Innovation Management, Kazan, Russia

Abstract. This article discusses the role of orthoses in correcting biomechanics for patients with diabetic foot syndrome. It also analyzes literature on the use of specialized orthopedic shoes to address biomechanical foot issues and complicated forms of diabetes mellitus. Today, the general requirements for designing orthopedic shoes for patients with diabetes are described: a stiff sole with an artificial cushion; a suitable volume, a wide sole, an insole without a memory function; a thermally changeable elastic material; a minimum number of seams in the lining; an elastic upper and lining material in the toe area of the shoe; an increased fullness and additional volume in the toe region of the shoe, an angle of the bevel at the toe end of the sole, and the ability to adjust the interior volume of the shoe by using a hard heel that is stabilized with additional softness from the lining, as well as a smooth, non-traumatic upper. Indications for orthopedic unloading in patients with diabetic foot syndrome are highlighted. There is a negative approach towards conservative methods of treating patients with diabetic feet, but amputation in these cases cannot be considered a positive outcome of treatment. Nearly 70 to 90 percent of ulcers in this patient group heal without amputation. Techniques using specially designed shoes are less expensive and more cost-effective than limb loss. The use of orthotic shoes in diabetic foot patients serves as a method of both correction and rehabilitation.

1 Introduction

Diabetes mellitus is one of the most rapidly growing health challenges in the 21st century. In the last two decades, the number of adults with diabetes has more than tripled. It is estimated [1] that diabetes mellitus and its complications accounted for the death of 6.7 million people in 2021, which means that one person died every 5 seconds due to diabetes. Diabetic foot syndrome (DFS) refers to a group of destructive lesions that develop in the lower extremities as a result of diabetes. About 85% of these are trophic ulcers in the feet [1-17]. In addition, there are non-purulent, destructive damages to the bone structures in the extremities (diabetic neuroosteoaropathy) and the persistent consequences of these processes that belong to the

* Corresponding author: korejba_k@mail.ru

SDS. This diagnosis is often made for patients who have a high risk of developing purulent-destructive lesions, such as a pronounced foot deformity or a history of ulcers, etc. The following foot deformities most often lead to the development of ulcers in diabetes mellitus: deformation of the fingers and the front of the article, hollow foot and flat foot, collapse of the middle part of the foot.

Flat feet and polovarus deformities, rigid claw-like and hammer-like fingers, and hallux valgus of the first toe are common complications. Other complex deformities, such as Charcot's disease, can also occur, the consequences of minor amputations or resections of the foot can be severe. The dramatic consequences of SDS can be amputations, both high and low, as well as death from complications caused by purulent necrotic processes. 85% of cases of trophic ulcers result in the amputation of an extremity.

2 Materials and methods

According to statistics, approximately 85% of patients who undergo amputation at the foot level are able to return to work with adequate foot unloading. About 67% of patients are socially adapted following amputation at the shin level, and only 25% of patients can care for themselves following amputation at the hip level. Additionally, 77% of elderly patients are unable to return home following amputation procedures [3, 4].

A proper orthosis selection is a crucial component of the treatment for diabetic foot. Orthosis (special shoes, insoles, etc.) is a means of restoring the lost forms and functions of the musculoskeletal system. Orthoses are external orthopedic devices designed to correct, stabilize, and compensate for disorders of the musculoskeletal system, they also provide protection and relief. Orthoses for patients with foot pathology are made from a variety of materials - from soft foam pads to hard plastic, most often using a substrate of laminated graphite or carbon fiber. The orthopedic insoles create optimal support, simulating a return to natural conditions - walking on natural ground. Due to reduced sensitivity in the extremities, diabetic patients often do not feel discomfort during walking, even during the moment of overload. Corns are formed which easily degenerate into long-term, non-healing wounds. Individually selected orthopedic shoes help prevent the formation of calluses, scuffs, and corns, and prevent the progress of SDS. Therefore, when choosing an orthosis, it is necessary to proceed from the following basic principles: 1. When prescribing an orthosis, its stability should be taken into account — support is needed for at least three points, which helps reduce the axial load on the foot; 2. It is necessary to ensure comprehensive coverage of the foot for its supportability; 3. Orthoses should be made of elastic materials with rigid elements, allowing for maintaining reverse differentiation during treatment; 4. Dynamic gas and moisture exchange are necessary, which increase comfort when wearing an orthosis; 5. Orthoses should have a pronounced heat-saving effect, which helps to improve blood circulation, especially in the arterial part of arteriovenous anastomoses, this is most important for SDS; 6. The materials used in orthosis manufacture should be hygienic and hypoallergenic and should not lose their quality during sanitation and disinfection; 7. Access to the affected areas is required with minimal time and material costs; 8. The possibility of using an orthosis both as an independent therapeutic agent and in complex therapy with the use of therapeutic and surgical treatment techniques for DFS is needed; 9. By improving blood circulation, orthosis should contribute to the rapid absorption of drugs used topically (externally) and improve their therapeutic effect.

Almost 80% of lower limb amputations in patients with diabetes occur due to improperly selected shoes [10, 11, 15, 16]. The selection of orthoses is done individually: the compression level of at least 2nd Class (15-21 mm Hg), dimensions (XS, S, M, L, XL, XXL), which are determined when measuring the lower leg in the lower third immediately above the ankles, or top sizes from 1st to 5th at determining the oblique size of the ankle joint.

Due to the numerous objective and subjective difficulties in treating SDS, misconceptions have taken hold, one of which is a nihilistic approach towards SDS. It implies that the treatment for this pathology is ineffective, and any patient with lesions of the lower extremities as a result of diabetes mellitus will, sooner or later, be amputated. «Amputation? Nein, Danre!» ("Amputation? No, thank you!") — this is the title of a book by one of the pioneers in the treatment of SDS in Germany [14]. One prevented amputation, in addition to the obvious benefits for the patient, retains funds sufficient for his socio-psychological rehabilitation and outpatient supervision [5,6]. The introduction of modern foot lesion correction in diabetes mellitus, considering a multidisciplinary approach, and also full-fledged prevention (mainly supplying patients with special shoes), as well as patient training, reduces the frequency of amputations by 43-85% [3, 4]. One of the main mechanisms of the development of trophic ulcers in diabetes mellitus is associated with the presence of overloaded areas of the feet on the background of neuropathy [2,7]. It has been proven that orthopedic shoes and orthotics reduce the risk of ulceration in DFS by 2 to 3 times, which means they have a more effective preventive effect than many medicines prescribed for this purpose. According to a randomized clinical trial, after 1 year of using individually selected shoes for diabetic patients, the risk of recurrence of trophic ulcers decreased by 45% [13]. The use of special shoes in patients with diabetes mellitus can be attributed to both therapeutic and rehabilitation measures. In order to successfully carry out rehabilitation and achieve the goals set for each case, it is necessary to adhere to the basic principles of rehabilitation measures: complexity, early onset, phasing, continuity, consistency, individual approach, active participation of the patient in the rehabilitation process [12]. The early start of rehabilitation efforts is necessary in connection with the most active processes of restitution and regeneration during this period, as well as with the gradual restructuring of human attitudes towards changed conditions [7, 9]. In chronic diseases, it is possible to do so with timely diagnosis, preferably even before the development of a significant functional deficit or with its mild severity. In the early stages, in the management of any pathology, the proportion of treatments significantly exceeds the proportion of rehabilitative measures, but over time (Fig. 1), this imbalance is reduced and there comes a point when rehabilitation becomes the main method for managing the patient on the background of supportive drug treatment.

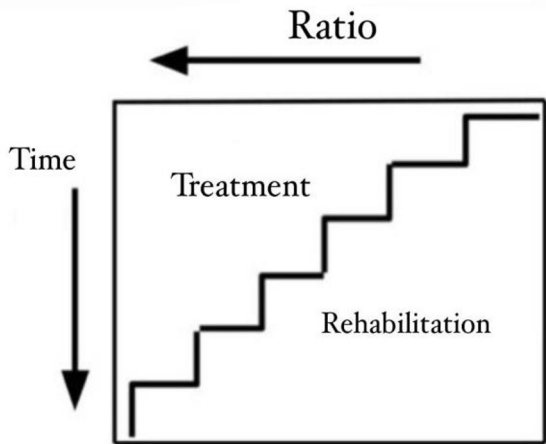


Fig. 1. The time ratio between treatment and rehabilitation for patients.

"... It is not always easy to draw a clear line between treatment and rehabilitation..." [8].

Types of orthopedic shoes for diabetic patients: 1. Ready-made shoes (foot without pronounced deformations, standard volumetric dimensions). 2. Custommade shoes (pronounced deformations, non-standard volumetric dimensions, a significant difference in the size of the right and left feet). The categories of patients with diabetes mellitus, according to the degree of their need for orthopedic products, are presented in table 1.

Table 1. Categories of patients with diabetes mellitus according to the degree of need for orthopedic products

Categories of patients	Clinical manifestations of SDS	Recommendations
Category 1: The low risk of SDS is in 50-60% of all patients	Feet without deformities: 1a — with normal sensitivity; 1b — with impaired sensitivity	Patients can (1a) purchase ready-made shoes at a regular store, but in compliance with certain rules for shoe selection, or (1b) they may need "ready-made" shoes with a typical cushioning insole.
Category 2: Moderate risk of SDS, is in 15-20% of all patients	Moderate deformities (hallux valgus I-II degrees, moderately pronounced beak -shaped and hammer-shaped fingers, flat feet, prolapse of the metatarsal heads, etc.)	Patients need to have "shoes on a ready-made shoe block" (usually with increased depth) with an individually made insole.
Category 3: The high risk of SDS is in 10-15% of all patients	Severe deformities, pre-ulcerative skin changes, a history of trophic ulcers, amputations within the foot, neuroosteoarthropathy	Patients need individual shoes with an individually made insole
Category 4: Patients with SDS, 5-7% of patients	Trophic ulcers and wounds at the time of examination, acute and subacute neuroosteoarthropathy	Orthopedic shoes are not effective. Unloading devices ("polubashmak", Total Contact Cast) are used until the wound heals or the end of the acute/ subacute stage of neuro osteoarthropathy. In the future, orthopedic shoes for both categories 2 and 3.

The main functions of wearable orthosis are: 1. To prevent horizontal friction on the plantar surface of the foot. 2. To not squeeze the foot from the side or above (even with deformities), and not injure the front part of the foot (the fingers) with a hard top. 3. To protect the foot from injuries and other adverse environmental factors. 4. To ensure sufficient ventilation of the foot and comfort and convenience when wearing it, putting it on and taking it off. 5. To give the user the opportunity to adjust the volume during the day.

The effectiveness of shoes lies in their ability to prevent the development of trophic ulcers, which are associated with foot injuries when walking. The effectiveness of shoes can be assessed using the following methods: a) by using pedography inside the shoes; b) to reduce pre-ulcerative changes in "risk zones"; c) to reduce the frequency of the formation of new ulcers.

The reasons why patients with SDS need special shoes are as follows:

1. Immobilization:

- as a result, posture is "straightened" because by redistributing the load on the ankle, knee, and hip joints, the lumbosacral joint is reduced;
- shoes are "responsible" for the dynamics of movement, while insoles are for static positioning;
- stress in the foot decreases due to redistribution of pressure in the plantar surface;
- biomechanics improve, and the structure of the feet is strengthened.

2. Decompression:

- improvement of the healing condition of defects in the skin and soft tissue of the foot.

The procedure for creating individual diabetic shoes:

- a) Measuring foot loads using special molds and creating an impression of the foot;
- b) scanning and creating a 3D model of the foot;
- c) three-dimensional reproduction of foot movement during walking;
- d) shoe design;
- e) manufacture of custom shoes taking into account the aforementioned requirements;
- f) creation of custom insoles for custom-made shoes, taking into consideration the biomechanics of each individual's foot.

Changing the shape of the foot and determining the size of orthopedic shoes: there are three main components to shoe size selection – length, width, and depth. The depth of the shoe is determined by taking into account the volume of the supinator. General requirements for the design of orthopedic shoes for patients with diabetes: 1. A rigid (rigid, unbending) sole, with artificial rolling; 2. The shoe is lifted by 8 mm because of the support (insole). Suitable volume, wide sole, removable insole; 3. An insole without a memory function. 4. A thermally changeable elastic material, preferably with silver ions, in the lining area; 5. The minimum number of seams in the lining ("seamless"); 6. There is no toe cap: the upper and lining materials are elastic (stretchable) in the toe area of the shoe; 7. There is increased fullness and additional volume in the toes of the shoes; 8. The angle of the bevel on the nasal part of the sole is 15°; 9. The ability to adjust the internal volume of the shoe using laces or fasteners; 10. A dense (hard) backing - a stabilizing heel with additional cushioning provided by the lining; 11. Heels with a beveled front edge, or a solid sole with no heel; 12. A smooth, atraumatic upper covering with the option for hygienic treatments (including antiseptic solutions).

Rules for wearing orthopedic shoes for diabetic patients:

1. Orthopedic shoes are only beneficial when worn constantly. 2. Shoes and insoles are a single unit, orthopedic insoles can't be transferred to other shoes. 3. Using individually made insoles in non-orthopedic shoes worn by patients is unacceptable. 4. In some cases, using insoles with complications of the local process is not practical. It is necessary to use lines, pilots and foot pads; 5. It is at least once a year necessary to produce new insoles (or part replacement of the material of the insole used). 6. If a profiled insole is necessary, it must be manufactured strictly individually (according to the imprint), completely replicating the relief of the plantar surface of the foot. 7. The right and left insoles can't be the same due to shape asymmetry. 8. It's necessary to wear orthotic shoes at home. 9. The patient should follow the rules for foot care. 10. Regular examination by a qualified orthopedist is required.

The patient and doctor should understand that rehabilitation is a long process. Success in achieving the goal depends on mutual trust between all participants in the program, both the patient themselves and the medical team, social workers and relatives. When wearing orthopedic shoes, the stability of the entire body increases, making it easier for the patient to maintain their balance. This also improves the quality of life for patients with diabetes who have difficulties with spatial coordination. People with diabetes are characterized by what is called "fatigue or chronic injuries." The use of orthoses and special diabetic shoes serves as a prevention of this problem.

3 Conclusions

1. The importance of providing patients with diabetic foot syndrome with high-quality orthopedic shoes is beyond doubt.
2. Managing the unloading process of the lower extremities in patients with diabetic foot syndrome is one of the priorities.
3. At the present stage, special shoes and orthoses should be considered as means of correcting biomechanical disorders of the foot, to which it is important to apply the same

strict criteria for evaluating quality and effectiveness as for medicines in evidence-based medicine, including randomized controlled trials.

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